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OF

The Terrestrial Electric Observatory

OF

FERNANDO SANFORD
Palo Alto, California

VOLUME III

Summary of Observations on Earth Potential,
Air-Potential Gradients, and Earth-Currents
for the year 1925

Palo Alto, California
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STANFORD UNIVERSITY
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CONTENTS

SUMMARY OF OBSERVATIONS ON EARTH POTENTIAL, AIR-POTENTIAL GRADIENTS, AND EARTH-CURRENTS FOR THE YEAR 1925

ON SOME INSTRUMENTAL ERRORS NOT RECOGNIZED IN PREVIOUSLY PUBLISHED RECORDS

Temperature Rotation in Metal and Quartz-Fiber Suspensions

On March 22, 1925, the switch between a quadrant electrometer and the air terminals which were being used in measuring the diurnal variation of atmospheric potential gradient was inadvertently left open, thus leaving the electrometer quadrants insulated. When the photographic record was developed on the following morning it was found that the electrometer needle had gone through a diurnal oscillation similar to, but smaller than, the oscillation which previously had been attributed to the diurnal variation in air-potential gradient.

Many experiments were made to determine the cause of this variation. Another electrometer which was being used to record the diurnal variation of earth potential had its quadrants connected and insulated and was found to give a similar, though somewhat smaller oscillation than that given by the air-potential electrometer.

It was found that discharging the needle, earthing the needle and the quadrants, even removing the quadrants, did not appreciably affect the diurnal oscillation of the needle. Neither did changing the location of the electrometer from one pier to another make an appreciable difference in the daily oscillation of the needle. The air-potential electrometer was provided with a phosphor-bronze ribbon suspension 14 centimeters long and the earth-potential electrometer had a silver suspension of approximately the same length, but the daily curves given by the two electrometers were very similar.

A third suspension of heavier phosphor-bronze ribbon was mounted in a magnetometer from which the magnet had been removed, and was provided with a small concave mirror and a piece of wax crayon for a weight at its lower end. Figure 1 (p. 6) shows the actual magnitude of the diurnal oscillation of the three suspensions on the same day, the horizontal lines in the figure being one centimeter apart. The curve of the silver suspension is marked *A,* the phosphor-bronze suspension in the air-potential electrometer *B,* and the suspension in the magnetometer tube *C.* The two electrometers stood on the same pier and recorded upon the same drum, and the magnetometer stood on another pier facing at right angles to the other two instruments, and recorded on a different drum. The

source of light and the recording drums were one meter distant from the suspension mirrors, and the records were accordingly made at the centers of curvature of the mirrors.

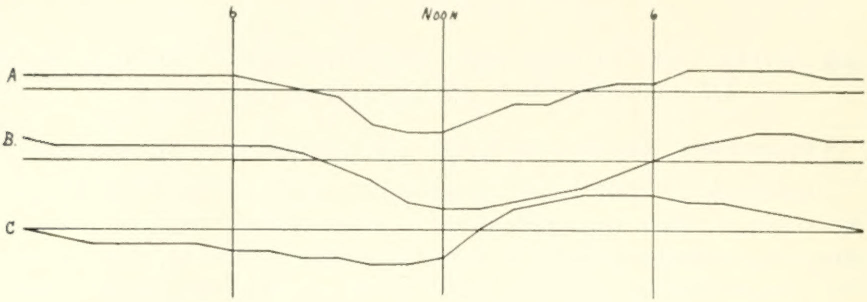

FIGURE 1

Diurnal temperature oscillations of three electrometer suspensions on the same day.

The suspension which had been used in the air-potential electrometer was transferred to the magnetometer and its diurnal oscillations again recorded. Figure 2 shows the curves given by this suspension while in the electrometer on two different piers and while in the magnetometer and on a third pier. The scale is in this case the same as in Figure 1.

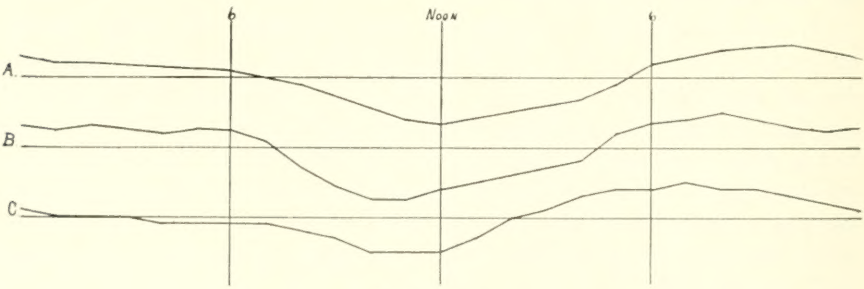

FIGURE 2

Diurnal temperature oscillations of the same electrometer suspension on different days and under different conditions.

Two of the phosphor-bronze suspensions were replaced by quartz fibers. One of these fibers, which was 14 centimeters long, gave a daily oscillation of 9 degrees of arc. This fiber also showed a permanent drift in the same direction of about one degree a day for six days. Another quartz fiber about 5 centimeters long gave a diurnal oscillation of about two degrees, but in the opposite direction to the other suspensions.

A D'Arsonval galvanometer with a heavy coil suspended in oil and a heavy phosphor-bronze suspension 5 centimeters long gave a regular

diurnal oscillation of about 3 centimeters range on the recording sheet at the center of curvature of the mirror. Three different suspensions were tried on this galvanometer and all gave similar oscillations. Figure 3 shows the mean diurnal oscillations of the galvanometer suspension and of a quartz-fiber suspension of the same length. The curves are drawn to the same scale as Figures 1 and 2.

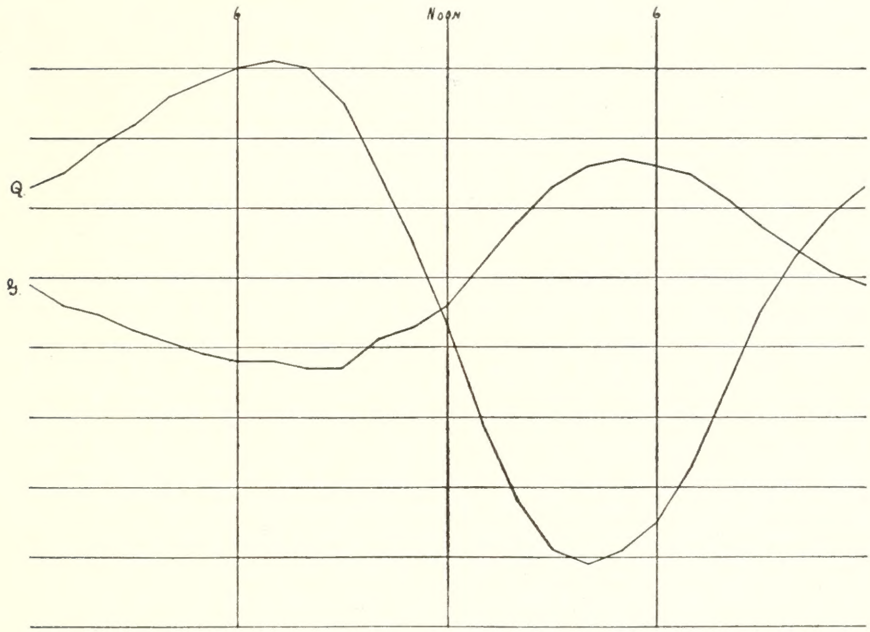

FIGURE 3

Diurnal temperature oscillation of a phosphor-bronze galvanometer suspension 5 centimeters long and a quartz-fiber suspension of the same length. The galvanometer suspension curve is marked *G* and the quartz-fiber suspension curve *Q*.

After testing all the other possibilities (and impossibilities) which came to mind, an electric heater was placed in the instrument room and the temperature was varied as rapidly as possible through a considerable range. It was then found that the rotation of the suspensions followed the temperature changes.

The reason for this temperature oscillation does not appear. In both the electrometers the suspensions are wholly within the metal cases of the instruments. The beam of light which passes through a glass window and falls upon the small concave mirror does not strike either suspension. In the magnetometer the suspension is contained in a glass tube and receives some light on one side from the lamps used for giving the

photographic record, yet so far as can be seen from Figure 2 the diurnal oscillation was not greater in this instrument than in the electrometer. All the metal suspensions rotate counter-clockwise (when looked at from above) while the temperature is increasing, and clockwise while it is decreasing.

Both electrometers are on heavy insulated bases supported on leveling screws, while the magnetometer stands on a brass tripod 10 centimeters high. To see whether the oscillations of the suspension in this instrument were due to the unequal expansion of the tripod legs, these were placed in a pan of water 7 centimeters deep for four days, but the diurnal oscillation was not decreased by the water.

While the tilting of the support may cause a rotation in a metal ribbon suspension, it is not easy to see why it should do so in the case of a quartz fiber, yet the quartz fibers gave much greater oscillations than the metal suspensions.

A silk-fiber suspension was tried in the magnetometer, but its deflection was irregular and was greater than could be recorded on my six-inch record sheet.

In Figure 4 is shown the diurnal temperature variations of the silver suspension used in my earth-potential electrometer on 14 days of different temperature ranges. The curves are drawn to scale when the horizontal base lines are taken one centimeter apart. The temperature range in Fahrenheit degrees for each day is indicated on the margin.

It is plain that these temperature rotations have introduced an important error in all of my previous work on variations in earth-potential and in air-potential gradients, and have, at least, given cause to question the work of other observers which has been done with similar instruments. The experience gained from testing seven different metal suspensions and three quartz suspensions suggests that a temperature oscillation is a common characteristic of such suspensions when used in a room where the temperature is not nearly constant. For this reason my records of 1925 made previous to July 15 are only briefly referred to in this publication.

In this connection, attention should be called to the fact that the very close agreement between the earth-potential and air-potential curves shown in my records of 1924 are partly due to the fact that the two electrometer suspensions gave very similar temperature curves which were fairly constant, and which had a daily range more than half as great as the average range of the earth-potential variations. However, the corrected curves of the present year, while more irregular since the smooth temperature curves have been taken out of them, still show very definitely the relation between the two phenomena which was predicated upon the basis of last year's records.

Since July 15, 1925, each day's record of earth-potential and air-potential gradient has been corrected for temperature by subtracting from the hourly deviations the corresponding temperature variations for a day having the same total temperature range. The results of this correction are that the maxima and minima of positive potential are moved toward the earlier hours of the day, and the curves are somewhat less smooth than before.

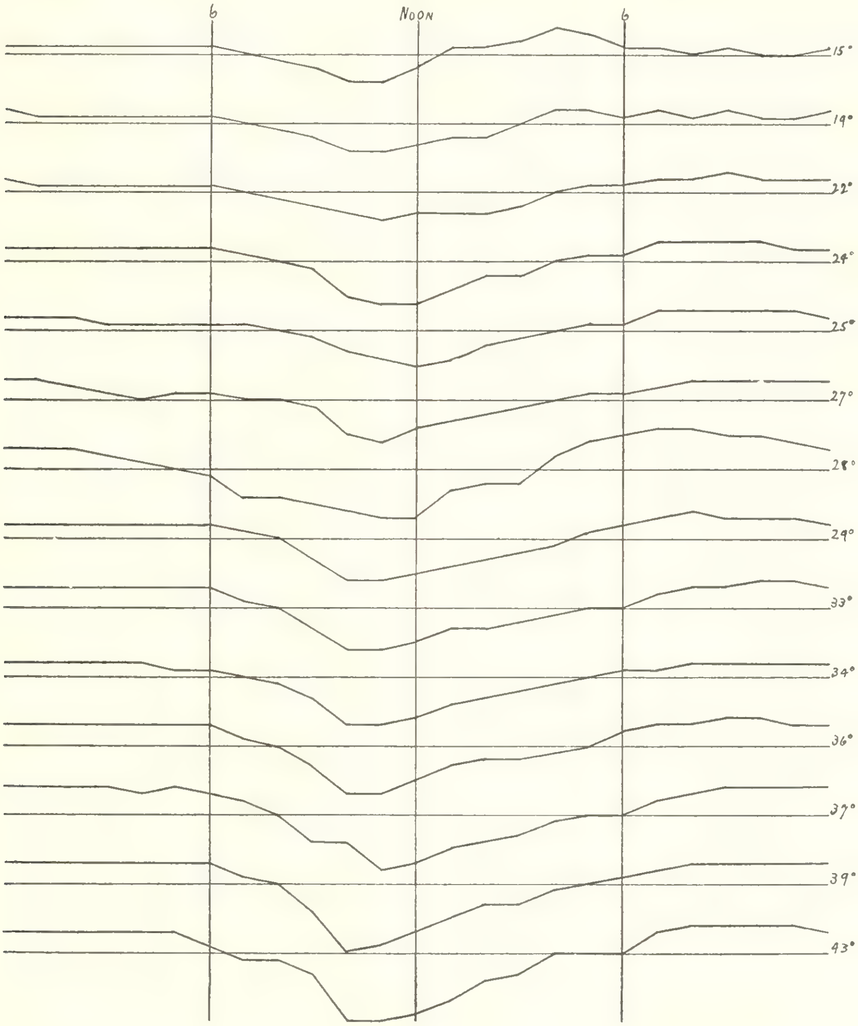

FIGURE 4

Diurnal temperature oscillation of a silver electrometer suspension on 14 days of different temperature ranges. The daily temperature ranges are indicated at the right.

In Figure 5 are shown the corrected and uncorrected curves for 29 days in October, 1925. The uncorrected curve is shown by the dashed line and the corrected curve by the continuous line.

Another source of inaccuracy, though not a serious one, is found in the difficulty of getting a straight base line from which to measure the hourly deviations of the electrometer records. From the beginning of this work, the base line has usually been found to be slightly curved, the deviation generally having been of the order of one millimeter in the 48 centimeters of length of the record. However, at times the deviation

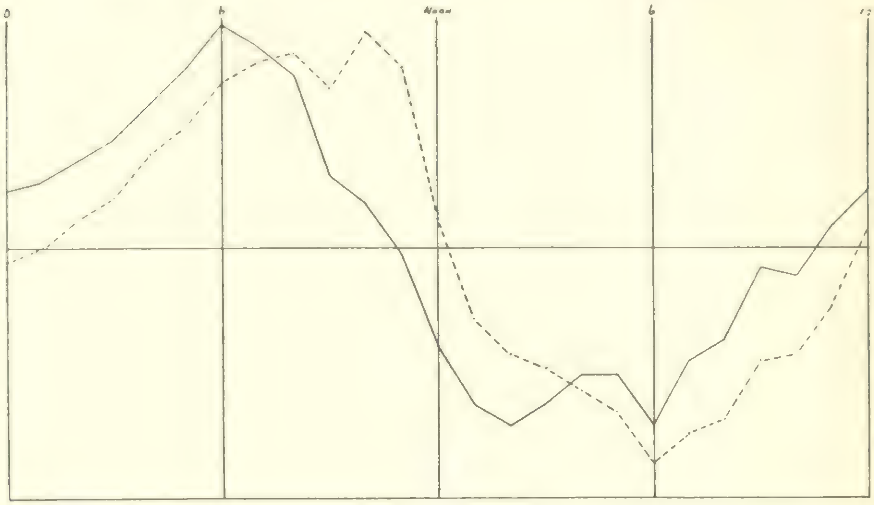

FIGURE 5

Corrected and uncorrected curves of diurnal variation of earth potential for 29 days in October, 1925. The continuous curve is corrected for temperature variation and the dashed curve is not.

is much greater than this amount, being sometimes as great as 4 or 5 millimeters. In measuring the records it has been the custom to draw a straight line between the ends of the base line and to measure the deviation of the electrometer records from this line.

Numerous experiments have been made to locate the source of the variation in the base line, and there seem to be two principal causes for this variation. One of them is found in the source of light used. In all my measurements the light source has been an ordinary "Mazda" incandescent lamp of from 25 to 40 watts, placed on a horizontal base so that the filaments are as nearly as possible vertical. A hollow cylinder with a vertical slit on one side is placed over the lamp, and the concave mirrors

of the electrometers and the fixed one used to give a base line are so set as to project an image of one of the lamp filaments seen through this slit on to the recording sheet. The lamps when once set up are kept lighted until they are burned out, which may be a period of a number of weeks or months.

By projecting an enlarged image of such a lighted lamp upon a screen at a distance of several feet from the lamp and marking with a pencil and ruler the edge of a filament image on the screen, this image is found to change its position somewhat during the day. This change in position does not seem to correspond closely with the change of current through the lamp. The voltage on the lighting circuit varies from about 120 volts to about 115 volts during an average day. There is a somewhat greater movement of the filament when the voltage is at its highest, but by introducing an electric heater parallel with the lamp, which cuts the voltage down about 6 volts, the change in the position of the filament is very slight.

Since the image of the filament is projected on the recording drum at the center of curvature of the mirror, the deviation of the filament can account for but a very small part of the deviation of the base line sometimes recorded upon the record sheet. The rest of the deviation seems to be associated with the changes in room temperature, somewhat as are the deviations of the various suspension fibers. The concave mirrors used in projecting the image for the base line have been mounted upon stems of iron, brass, glass, hard rubber, carbon, whalebone, and wood, and have been fastened on in various ways. At the time of this writing there are two concave mirrors mounted upon the same brass stem, one above the other, and adjusted so as to focus the image of the same filament upon the recording drum. One of these is fastened by shellac to a paper collar, which is shellacked to the brass stem, and the other is stuck to the stem with soft wax. The two mirrors give curved lines which deviate in opposite directions from a straight line. Most of the deviation is in the day time, and it seems approximately to follow the temperature variations in the instrument room.

Diurnal Variation in Earth Potential for 1925

The method of measuring what is here called the variation of earth potential at this particular station has been described in both Volume I and Volume II of this *Bulletin,* and is again briefly described on page 14. A diagram of the apparatus used is shown in Figure 8.

Owing to the experimental errors introduced by temperature changes in the instrument room which were not recognized until March 22, and to the fact that no daily record of temperature ranges was kept previous to this date, the records for January and February cannot be corrected

for this error. After the discovery of this diurnal disturbance over three months were consumed in running down the cause of the disturbance, in trying to find a suspension which was not caused to twist by a change of temperature, and, finally, in preparing a table of variation with temperature of the suspensions used in my different instruments. This last determination was made necessary by the fact that no room of approximately constant temperature was available for this work.

The uncorrected curve for mean diurnal variation of earth potential for January and February is given in Figure 6. Since the sensitivity of

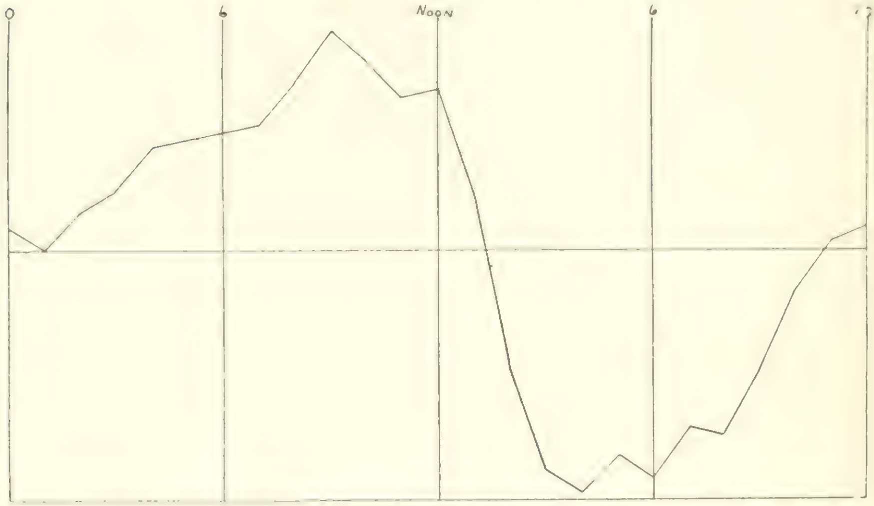

FIGURE 6

Uncorrected curve for mean diurnal variation of earth potential for January and February, 1925.

the electrometer was not high and the temperature ranges were large for these two months, the curve is undoubtedly much influenced by temperature variations.

For the remaining months of the year, beginning with July 15, the earth-potential, air-potential, and earth-current records have been corrected for temperature variation by subtracting from the measured variation for each hour the temperature variation for a corresponding hour on a day of the same, or nearly the same, temperature range. In this way records have been secured for 144 days. Nine of these days were much disturbed, and will be discussed later. The mean variation for the other 135 days is given in Table I, and is shown graphically in Figure 7.

The essential difference between this curve and the curve of diurnal variation for previous years may be seen by comparing Figure 7 with

TABLE I

Mean Diurnal Variation of Earth Potential for 135 Days from July 15 to December 31, 1925

A.M.	1	2	3	4	5	6	7	8	9	10	11	Noon
	+1.5	+2.1	+2.6	+3.2	+3.7	+4.2	+3.6	+2.7	+0.9	−1.8	−2.8	−2.2
P.M.	1	2	3	4	5	6	7	8	9	10	11	12
	−2.7	−3.2	−3.1	−2.0	−1.4	−2.3	−1.5	−0.9	0	0	+0.7	+1.4

Figure 6. The principal effect of the temperature correction is to move the time of maximum positive potential from about 9:00 a.m. to 6:00 a.m. and the time of minimum positive potential from about 4:00 p.m. to 2:00 or 3:00 p.m.

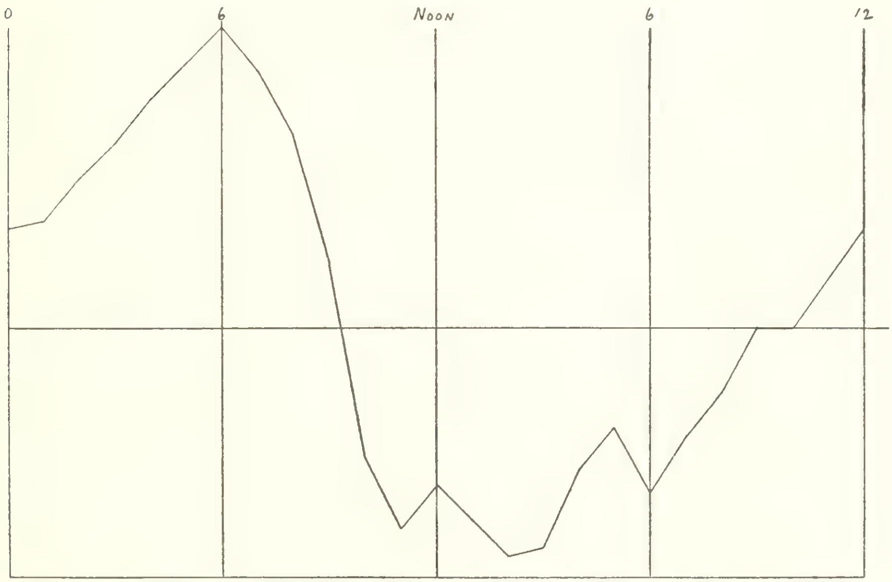

FIGURE 7

Mean diurnal variation of earth potential for 135 days, from July 15 to December 31, 1925. Corrected for temperature variations.

Comparison of Earth-Potential and Air-Potential Variations

In Volume II of this *Bulletin* are given data on the variations of earth potential and air potential during the same period, and the belief was expressed that the air-potential gradient is principally due to the induction of the earth's negative charge. In those investigations the air-potential gradient was measured between two points taken in the air, instead of between one point in the air and the earth. The air terminals were provided with points and with some radioactive material for ionizing the air in the region of the points, thus allowing the induced free charge to escape into the surrounding air while measuring the bound charge. In the case of the measurements covered by this report the air terminals were replaced by two hollow copper balls, such as are used for plumber's floats, one ball being 7 inches in diameter and the other 8 inches in diameter, the object being to prevent as far as possible the rate of escape of the induced free charge. The balls were suspended by very carefully insulated supports from the arms of a mast raised above the observatory building, which is only about 4 meters high. The upper ball was 3 meters above the lower one, which was 1.5 meters above the observatory roof.

As has been previously reported, there are a number of trees about the observatory which are taller than the mast, one eucalyptus tree about sixty feet distant being more than one hundred feet tall, so the potential gradient is very slight in the region of the suspended balls, there being usually a potential difference of about .5 volt between them. The variations of this gradient are accordingly measured on a quadrant electrometer having a sensitivity of about 4 centimeters on the recording sheet for one volt between the quadrants.

The electrometers used for measuring the variations of earth potential and air potential stand side by side on the same pier, and their deflections are recorded on the same drum. Their arrangement may be understood from the diagram given in Figure 8.

The method of measuring the earth-potential variations has been described in both of the earlier numbers of this *Bulletin,* and may be described again very briefly here.

In Figure 8, E represents the case of a quadrant electrometer which stands on a wooden pier inside a wire cage which is 4 feet square on the ground and 8 feet high. The quadrant pairs of the electrometer are indicated at a and b. One pair of quadrants (a) is connected to the metal case of the instrument, and through this to the surrounding wire cage and to the water system of Palo Alto. The other pair of quadrants is connected to an insulated conductor, C, inside the cage. The electrometer needle is charged from the battery B, which is inside a grounded metal box, and one pole of the battery is grounded through this box.

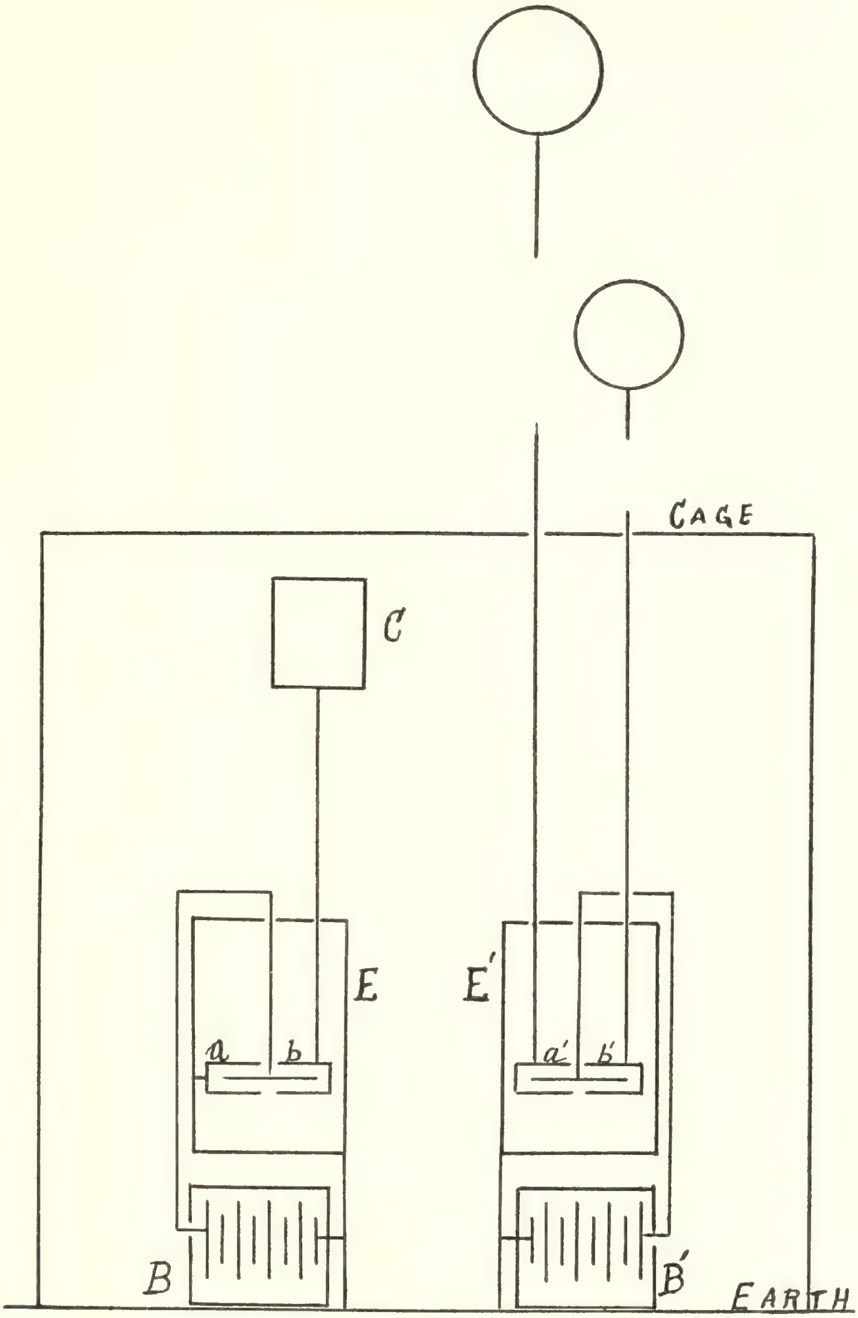

FIGURE 8

Diagram of arrangement of electrometers for recording earth-potential variations and variations of air-potential gradient.

The two pairs of electrometer quadrants are first connected, so that both they and the insulated conductor C will be at the potential of the earth. They are then separated and allowed to stand, while the deflection of the electrometer needle is recorded photographically by means of a beam of light reflected from a small concave mirror, attached to the needle, on to a strip of sensitized paper fastened around a revolving drum outside the cage.

The insulation of the conductor C, the effect of leakage from the needle to the insulated quadrants, and other matters influencing the accuracy of the results have been described in previous numbers of this *Bulletin*.

In the same way E' indicates the electrometer used for measuring the potential gradient of the air. The needle is charged, as in electrometer E, but from a separate battery. Both pairs of quadrants are insulated from the case of the instrument and are attached to the two balls mentioned above by means of insulated wires passing through the wall of the instrument room just below the roof. The electrometer case is earthed.

The charges on the two electrometer needles have been adjusted so that the deflections of both are of nearly the same magnitude. In this condition, the earth-potential electrometer is about twice as sensitive as the one used for measuring the air-potential variation.

The mean diurnal variation of potential difference between the two balls suspended as described above for 144 days, from July 15 to December 31, 1925, is given in Table II.

TABLE II

Mean Diurnal Variation in Potential between Two Insulated Copper Balls Suspended as Described in the Text

A.M.	1	2	3	4	5	6	7	8	9	10	11	Noon
	+2.1	+2.3	+2.5	+2.7	+3.4	+4.3	+5.8	+2.5	+0.1	−3.3	−3.0	−3.1
P.M.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	−2.9	−2.5	−2.8	−2.6	−3.0	−2.0	−0.3	+0.5	+0.5	+0.7	+1.3	+1.9

In Figure 9 this variation is shown graphically, and is compared with the daily variation of earth potential for the same period, the higher ball being compared with the grounded quadrants of the earth-potential electrometer and the lower ball with the insulated conductor, C, shown in Figure 8.

While the minor deviations are not the same in the two curves, and while each is subject to disturbances which do not affect the other, the

agreement of the two is so close as to strongly confirm the hypothesis that the potential difference between the two balls is due to the induction of the negative electric field of the earth, and that the diurnal variations in this potential difference are due, as are the potential variations on the earth, to the induction of the sun's negative charge.

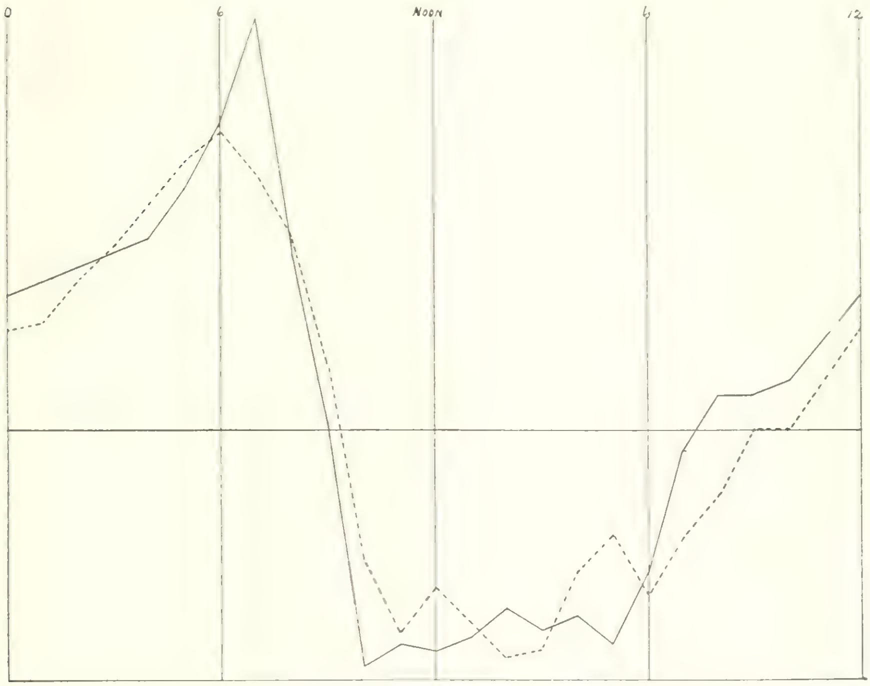

FIGURE 9

Comparison of mean diurnal variation of air-potential gradient with the corresponding variation of earth potential. The air-potential variation is indicated by the continuous curve and the earth-potential variation by the dashed curve. Both curves are corrected for temperature variation.

The arrangement of the apparatus is such as to reduce as much as possible the probability of the balls' being differently charged from the air, and also to reduce the rate of discharge of the induced free charges. The mean potential difference between the balls is not more than half a volt, and the curvature of the balls is so small as to make the potential gradient around them very slight. The wires leading from them to the electrometer are heavily insulated. Measurements are now being made in which the whole surface of the balls and the wires is well insulated, but no different results are expected.

Disturbances of earth potential.—It has already been mentioned that among the 144 days for which earth-potential records were obtained there were 9 days omitted from the average given in Table I. These days were those ending at 9:00 a.m. on August 13 and 22, September 9 and 10, November 19, and December 4, 15, 17, and 27. These nine days were of unusual range of earth-potential variation.

It has been mentioned in previous publications of this observatory that the records of diurnal variation of earth potential, like the records of variation of the magnetic elements, are sometimes greatly disturbed. The magnitude of these disturbances is hard to define. Sometimes the records are very irregular and jumpy, though the total range of variation may not be greater than on ordinary days. In selecting the nine most disturbed days of the period under consideration reference was had only to the range of variation from the median line at some one or more of the hourly intervals for which the records were measured. The range at one of these intervals may not be, and usually is not, the greatest range for the day, for large deflections of the electrometer needle frequently last but a short time, the changes at times being too rapid to impress themselves upon the photographic paper. In the case of the nine days chosen, the record of each one varied at some hour of the day two centimeters, or more, from the median line for the day.

It seems to be an almost universal rule of these disturbances that they are marked by a very sudden and very large deflection in the negative direction; that is, the quadrant pair which is connected to the inside of the cage and to earth becomes suddenly and strongly electronegative. It has commonly, though not always, been the case that these sudden deviations occur in the middle part of the forenoon, from about 8:00 a.m. to 10:00 a.m. A few very large deflections of this character have been recorded in the afternoon, and even in the night.

All of the nine disturbances referred to in this report occurred in the forenoon. In Figure 10 the mean of these disturbances is compared with the mean variation for the 135 days represented in Figure 7. The mean variation for the 135 days is shown by the dotted line and that for the disturbances is shown by the continuous curve. In preparing the curve for the disturbances, the mean variation for the 135 days was subtracted from the variation for each of the disturbed days, leaving only the part which was superimposed upon the mean variation by the disturbance. It is the mean of these superimposed disturbances which is shown in Figure 10, and not the mean variation for the disturbed days.

The cause of these peculiar disturbances is not known. They differ from the well-known magnetic disturbances (magnetic storms) in that the latter occur at the same time all over the earth, and consequently can

have no regular daily time of occurrence at any given place. The fact that these disturbances of electrical potential of the earth do occur at approximately the same time of day shows conclusively that they are related in some way to the hour angle of the sun at the place of observation.

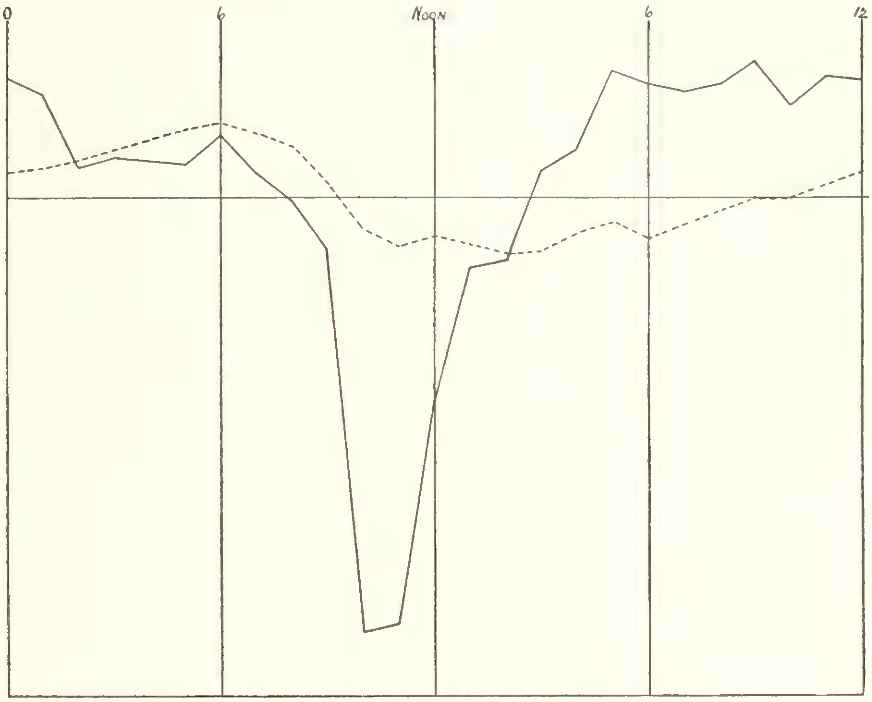

FIGURE 10

Earth-potential disturbances. The dashed curve shows the mean diurnal variation of earth potential for 135 days, and the continuous curve the superimposed mean effect of 9 disturbed days.

Earth-potential and air-potential disturbances.—While there are often very considerable disturbances of the normal air-potential variation, the earth-potential disturbances which are here being considered are not accompanied by corresponding disturbances of the air-potential gradient.

Earth-potential disturbances and sun spots.—It is well known that magnetic disturbances in the earth's field are related in some way to the solar activity as shown by sun spots. It has been observed and reported in previous numbers of this *Bulletin** that great disturbances of the electrical potential of the earth have occurred at times of great sun-spot dis-

* See especially Vol. I, p. 16.

turbance, and it was thought worth while to attempt to discover whether this is generally the case.

To test this question I have compiled the daily ranges of earth-potential variations at this station for all days on which visible sun spots were reported and for all days reported as being free from visible sun spots in the *Mount Wilson Magnetic Observations of Sun-Spots* as published in Volumes XXXV and XXXVI of *Publications of the Astronomical Society of the Pacific*, omitting months for which there were no visible sun spots and months for which there were no known days without sun spots. These omissions were made because the daily range of earth-potential variation is different at different seasons of the year. In all, sixteen months were used. During this period I have records of 176 days with and 205 days without visible sun spots. All days for which either the earth-potential records or the sun-spot records were incomplete were omitted.

The measurements of the records were made at hourly intervals, so the ranges given are usually not the maximum ranges of the 24 hours, but the maximum ranges at some given hour. The maximum range for the day is more likely to exceed the given range on disturbed days than on quiet days, since the disturbances sometimes take the form of very great deflections for short periods of time.

The mean daily range for 176 days on which there were visible sun spots was 15.2 millimeters on my record sheet, while the main daily range for 205 days without visible sun spots was 11.5 millimeters. This makes it seem probable that sun spots do usually affect in some manner the distribution of the earth's electric charge.

The conditions under which this comparison is made are such as to minimize the actual effect of the sun spots. Thus, each sun spot has been counted for every day upon which it was visible, while its effect upon the range of earth-potential variation may have been for only a small part of that time. Also, there were indications that some of the spots caused their greatest disturbance before they were observed, which in some cases was not until after they had passed the sun's central meridian.

On the other hand, there were several periods of disturbance which had all the characteristics of sun-spot disturbances when no sun spots were observed. Whether these disturbances were associated with magnetic disturbances upon the sun which are sometimes observed without visible sun spots, I am unable to say.

An attempt was made to find whether the magnetic intensity of the sun spots as measured at Mount Wilson bore any fixed relation to the magnitude of the earth-potential disturbance. For this purpose 26 rather isolated spots whose magnetic intensities are given were selected, and the ranges of the earth potential for seven days, including three days before

and three days after the passage of the spot across the central meridian of the sun, were compiled for each spot, and were compared with the reported values of the intensity of the magnetic field of the given spot. No quantitative relation between the two phenomena was observable.

It was also observed that the greatest earth-potential disturbance may occur when the spot is anywhere within two or three days of the sun's central meridian. For the 26 spots selected the greatest average range of disturbance (64 mm.) occurred on the second day after passing the meridian, while the days upon which the spots crossed the central meridian gave an average range of 59.5 millimeters.

Curves showing the mean earth-potential variation for 100 days with visible sun spots and 100 days without are given in Figure 11. The dashed

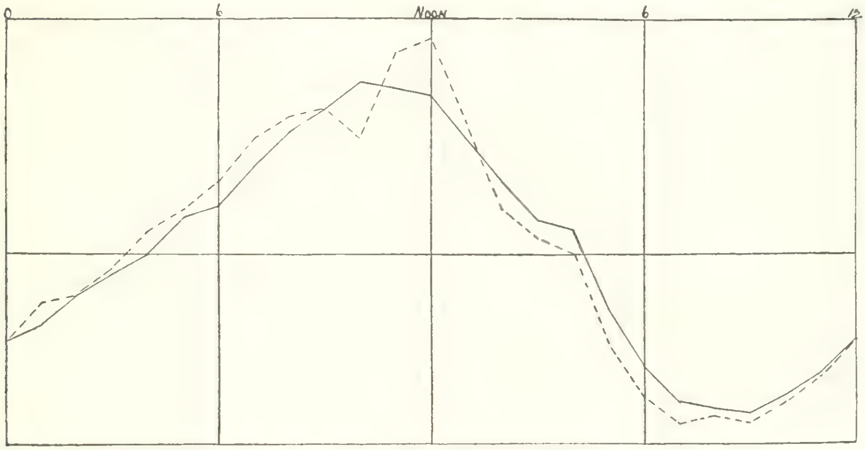

FIGURE 11

The continuous curve represents the mean diurnal variation of earth potential for 100 days without visible sun spots and the dashed curve the mean diurnal variation of 100 days with visible sun spots.

curve represents the days with visible sun spots and the continuous curve the days without. The principal difference is seen to be a marked falling off of the positive potential of the earth at about 10:00 a.m. and a conspicuous increase in the same from 11:00 a.m. to noon.

Earth-Currents

It was stated in Volume II of this *Bulletin* that the records of earth-currents were the least satisfactory of all the records made at this station. This was principally due to the disturbances caused by moving electric cars. The electric car service in Palo Alto was discontinued last summer, but

there still remains an interurban trolley line having one terminus at Palo Alto. Although this line is more than two miles distant from two of the grounds used in recording earth-currents, the range of its disturbance of the earth-currents between these two grounds is greater than the mean range of the diurnal variations of the undisturbed currents. Fortunately, the cars run at stated periods over this line, and their disturbance can, to a considerable extent, be separated from the normal variations of the currents.

Attention has already been called to the considerable error in previous earth-current reports from this station due to the temperature oscillation of the coil of the galvanometer used in recording the current variation. It will be seen by referring to Figure 3 of this volume that the daily oscillation of the galvanometer suspension was very great, thus making the direction of the resultant earth-current as shown in Figure 15 of Volume II unreliable. The same needs to be said of the data on the magnitude and direction of the potential gradient which are given in Table VII of the same volume.

Since discovering this temperature effect, records of 34 daily variations of earth-currents, 17 for grounds *A* and *B* (see Vol. II, p. 33) and 17 for grounds *A* and *C*, have been obtained and corrected for temperature variations. These two sets of records have then been reduced to the same distance between grounds on the assumption that the potential difference varies directly as this distance. Thus the distance between grounds *A* and *B* is 2.6 miles and that between *A* and *C* is 1.9 miles. The distance between *A* and *B* is accordingly 1.37 times the distance between *A* and *C*. The current intensities between *A* and *C* were accordingly multiplied by 1.37. This seemed allowable because the difference in resistance of the leads from *A* and *C* to this station is not great compared with the whole resistance in the galvanometer circuit, there being 1,600 ohms resistance introduced into this circuit to cut the deflections down to a convenient magnitude.

Both currents were then reduced to a true north-south and west-east direction. The diurnal variations of the two components are shown in Figure 12, while the direction and hourly magnitudes of the slope of potential gradient of the resultant of the two components are shown in Table III.

It will be seen that the direction of the earth-current in this region varies but little from a true south-east direction, the chief variation being due to an increase of the intensity of the N-S component in the middle of the day.

Since the electrons flow in the opposite direction to that of the conventional current, they are throughout the whole of the 24 hours flowing

from the higher region of the Santa Cruz Mountains to the marshes around San Francisco Bay. It is an interesting, though apparently not a significant, fact that this earth-current direction is almost exactly parallel

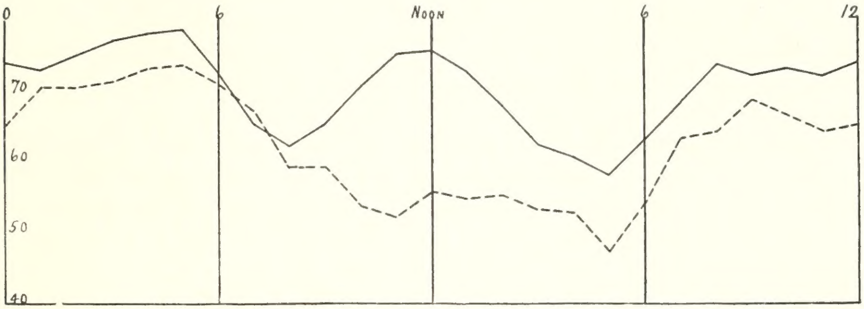

FIGURE 12

Mean diurnal variations of the N-S and W-E components of the earth-current at Palo Alto for the period September–December, 1925. The N-S component is shown by the continuous curve and the W-E component by the dashed curve.

to the great earthquake fault which runs about four miles south-west of my grounds. The actual potential gradient, as the table indicates, is quite variable, but probably averages about 35 or 40 millivolts per mile.

TABLE III

Magnitude and Direction of Slope of Electrical Potential Gradient in the Earth's Surface in Arbitrary Units at Different Hours of the Day, as Determined by Earth-Currents

Magnitude in Arbitrary Units

Hour	1	2	3	4	5	6	7	8	9	10	11	12
A.M.....	101	103	105	107	108	102	93	85	88	90	92	94
P.M.....	92	87	82	81	76	83	93	98	100	98	97	99

Direction in Degrees East of South

Hour	1	2	3	4	5	6	7	8	9	10	11	12
A.M.....	44	43	43	43	43	44	45	44	42	37	35	36
P.M.....	37	39	41	41	40	41	43	41	44	43	41	41

A comparison of the earth-potential variations with the resultant earth-current is difficult from the fact that the current changes its direction as well as its magnitude during the day. If the earth-current is due to the repulsion of the electrons in the earth by the negative charge of the sun,

the main current in low latitudes should, on the whole, be in a west-east direction. For stations farther north or south of the Equator the direction of this fundamental current will be changed at the times of the passage of the sun across their meridians, and it is conceivable, if not probable, that in high latitudes the N-S component may become the principal one.

From the Berlin measurements, published by Weinstein,* it may be seen that at noon and at midnight the N-S component is the principal one, and that it is in opposite directions at these hours.

The comparison of the W-E component as given here with the earth-potential variation as shown in Figure 7 is given in Figure 13, where the

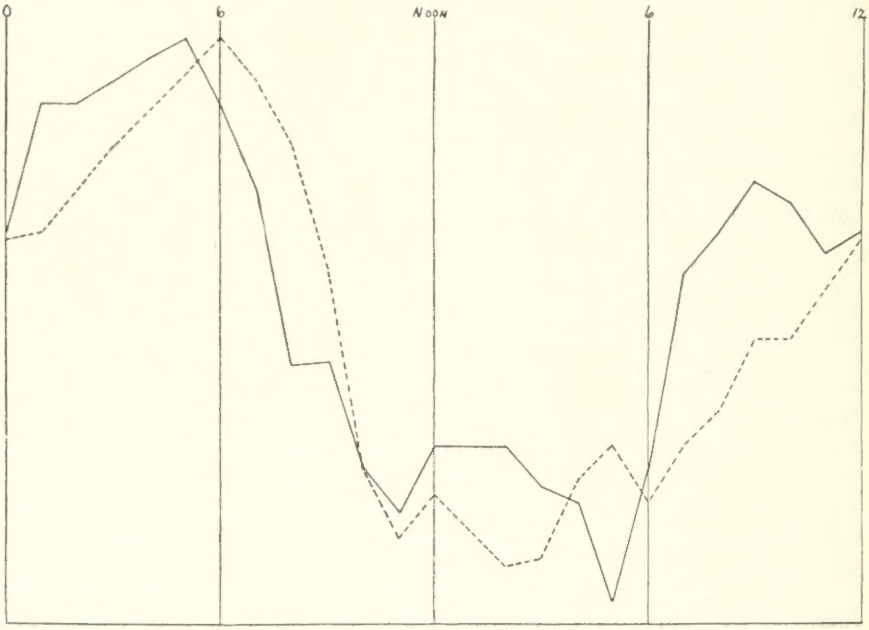

FIGURE 13

Comparison of the mean diurnal variation of earth potential with the mean diurnal variation in intensity of the west-east earth-current. The earth-current variation is shown by the continuous line.

units are so taken as to make the daily range of variation nearly the same in the two curves. The continuous curve shows the diurnal variation of the west-east earth-current, and the dashed curve the diurnal potential variation as shown in Figure 7. The resemblance between the two curves is such as, at least, to indicate a physical relation between the two phenomena which they represent.

* *Die Erdströme im Deutschen Reichstelegraphengebiet,* Tafeln.